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TECHNICAL MEMORANDUM

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WIND-TUNNEL INVESTIGATION AT HIGH SUBSONIC SPEED OF THE STATIC LONGITUDINAL STABILITY CHARACTERISTICS OF A WINGED REENTRY VEHICLE HAVING A LARGE NEGATIVELY DEFLECTED FLAP-TYPE CONTROL SURFACE

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By Paul G. Fournier

SUMMARY

An investigation has been made in the Langley high-speed 7- by 10-foot tunnel to determine the feasibility of using a flap-type control surface to provide longitudinal trim and stability throughout an angle-of-attack range from -2° to 90° on a clipped-delta-wing configuration, having an aspect ratio of 1.12, a taper ratio of 0.29, and a leading-edge sweep angle of 63°, considered for reentry from satellite orbit. The model was tested at Mach numbers from 0.60 to 0.90 with corresponding Reynolds numbers of 2.76×10^{6} to 4.03×10^{6} based on the basic-wing mean aerodynamic chord. The control surface consisted of a large trailing-edge flap that extended outboard of the wing tips. Vertical tails attached to the control surface at the wing-tip station moved with the control surface.

The control arrangement provided longitudinal trim and stability over most of the angle-of-attack range. However, the configuration was unstable at angles of attack from approximately 12° to 24°, especially at the lower Mach numbers.

INTRODUCTION

The problem of providing adequate stability and control for manned space vehicles during reentry through the earth's atmosphere is one that has arisen in the consideration of orbital and space flight. Two types of reentry satellites that have been considered are wingless (refs. 1, 2, and 3) and winged (refs. 4, 5, and 6).

One winged-type vehicle reenters the atmosphere at an angle of attack approaching 90° in order to utilize the advantages of a blunt body in minimizing aerodynamic heating (ref. 3). It uses lift to control deceleration loads and further reduce aerodynamic heating (ref. 7). Aerodynamic heating of specific components is not a primary concern of the present investigation. The winged vehicle would allow for a controlled flight path, and thus a wide selection of landing points.

Inasmuch as the center of pressure during the high angle-of-attack phase (90°) of reentry would be expected to be located close to the centroid of the wing plan-form area, the vehicle would probably be L
designed so that the center of gravity would be located at this point 6
in order to minimize the trim requirements during reentry. However, 2
subsonic data of reference 8 indicated that the basic clipped-delta- 1
wing configurations, having an aspect ratio of 1.12, a taper ratio of 0.29, and a leading-edge sweep angle of 63°, which are stable about the centroid of area at an angle of attack of 90° become unstable at lower angles because of a forward shift of the aerodynamic center. In the investigation in reference 8, attempts were made to alleviate this instability by the addition of wing-tip panels to keep the aerodynamic center behind the moment center. In principle, the panels would fold about a chordwise hinge line into the airstream as required to maintain longitudinal stability.

The present report presents another method of providing stability and control during reentry. This method utilizes flap-type controls which are deflected about spanwise hinge lines to obtain stability and trim at various angles of attack during transition to normal flight attitudes.

Data for the present report were obtained in the Langley high-speed 7- by 10-foot tunnel for Mach numbers of 0.60 and 0.80 through an angle-of-attack range from -2° to 90° and for a Mach number of 0.90 up to an angle of attack of 22°. These Mach numbers represent a Reynolds number range from approximately 2.76×10^6 to 4.03×10^6 based on the wing-alone mean aerodynamic chord. The data are presented herein with limited analysis.

SYMBOLS

The forces and moments are reduced to coefficient form and are referred to the stability system of axes illustrated in figure 1. Moment coefficients are presented about the centroid of area of the respective wing. However, all coefficients are based on the area, span, and mean aerodynamic chord of the basic wing (fig. 2). The coefficients and symbols used are defined and listed as follows:

the angles of attack are discussed in reference 8. The basic wing was a modified delta wing (also used in ref. 7) having an aspect ratio of 1.12, a taper ratio of 0.29, and a leading-edge sweep angle of 63°.

The control surface was a large flap that extended outboard of the wing tips. The flap was attached to the upper surface of the wing and simulated a split flap wherein the wing formed the fixed lower part of the flap. The trailing edge of the flap and the basic wing coincided at zero flap deflection. Flap deflections from 0° to -105° were used in the tests. Vertical tails were attached to the control surface at the
wing-tip station and moved with the control. A sketch of the vehicle in L
the reentry configuration is shown in figure 2(c). The wing and control 6
surfaces were flat-plate sections with rounded leading edges and tapered 2
trailing edges. Tests were also made to determine the effects of removing 1
a portion of the wing rearward of the control hinge line. The modified wing and its centroid (reference center of gravity) are indicated in figure 2(b). Details of the control, as well as the fuselage and wings, are given in figures 2(a) and 2(b).

Geometric characteristics of the model are given in table I, and a photograph of the basic wing and fuselage mounted in the Langley high-speed 7- by 10-foot tunnel is given as figure 3.

TESTS AND CORRECTIONS

Lift, drag, and pitching moment were measured from tests made through an angle-of-attack range from -2° to 90° for Mach numbers of 0.60 and 0.80 and through an angle-of-attack range from -2° to 22°, limited because of balance load limits, for a Mach number of 0.90. The corresponding Reynolds number based on the basic-wing mean aerodynamic chord varied from 2.76×10^6 to 4.03×10^6.

The control surface was positioned in 5° increments in the deflection range from 0° to -15° for the angle-of-attack range from -2° to 22°. Increments of 15° were used in the deflection range from -15° to -105° for angles of attack from 22° to 90°.

Angle-of-attack ranges for the various control deflections were generally restricted to regions near longitudinal trim. All data computed were based on the geometric characteristics of the basic wing.

Jet-boundary corrections determined by the method of reference 9 and blockage corrections determined by the method of reference 10 were found to be negligible and were, therefore, not applied to the data. The angles of attack have been corrected for the deflection of the sting

C_D'	drag coefficient, $\frac{\text{Drag}}{qS}$
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
$C_{L,trim}$	lift coefficient at trim angle of attack
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
$\bar{c}$	basic-wing mean aerodynamic chord, ft
$(L/D)_{trim}$	lift-drag ratio at trim angle of attack
M	free-stream Mach number
q	free-stream dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft
r	radius
S	area of basic wing, sq ft
V	free-stream velocity, ft/sec
X,Z	longitudinal and vertical axes, respectively
W	weight of vehicle (total)
W_c	weight of control surface
α	angle of attack, deg
α_{trim}	trim angle of attack
δ_t	control-surface deflection angle (negative when trailing edge is up), deg
ρ	mass density of air, slugs/cu ft

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APPARATUS AND DESCRIPTION OF MODEL

The investigation was made in the Langley high-speed 7- by 10-foot tunnel on a sting-support system. Details of the apparatus for obtaining support system and balance under load. No attempt was made to determine the sting-interference effects.

DISCUSSION

The static longitudinal stability characteristics of the model with the basic wing with and without the control are presented in figure 4. These data show that, generally, the control provided longitudinal trim
L throughout the range of angle of attack and Mach numbers of the
6 investigation.

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1 As the angle of attack was increased, the model with $\delta_t = 0^\circ$ showed a pitchup tendency at angles of attack between 7° and 10° depending on the Mach number. It should be noted that there was a range of angle of attack between about 12° and 24°, depending on the Mach number, where the configuration was unstable. This instability can be attributed to stalling of the control surface outboard of the wing tip because it is operating in the large upwash field outboard of the wing tips.

The static longitudinal stability characteristics of the complete model with the basic wing and with the modified wing (see fig. 2(b)) at $M = 0.60$ are presented in figure 5. A comparison is presented in figure 6 of the trim lift coefficient, the trim lift-drag ratio, and the control deflection required for trim for the model with the basic wing and the modified wing through the angle-of-attack range. These data show that the modified wing provides lower trim lift coefficients, higher lift-drag ratios, and larger required control deflections than the basic model at a given angle of attack.

As indicated previously, the purpose of a large flap-type control was to control the aerodynamic-center location and keep it rearward of the center of gravity to maintain stability. However, deflection of the control also causes a change in the location of the center of gravity. Deflection of the control from -90° to smaller angles moves both the aerodynamic center and the center of gravity rearward. It was of interest, therefore, to determine which of these effects would be predominant. Figure 7 presents the rearward center-of-gravity shift as a function of the ratio of control-surface weight to total vehicle weight W_c/W with the assumption that the control surface is of uniform weight per unit area. The figure indicates that for values of W_c/W greater than 0.21 and for $M = 0.60$, the rearward shift in center of gravity puts it behind aerodynamic center; therefore, the configuration would become unstable with the control at zero deflection.

Figure 8 shows the effect of 2.5-percent wing-mean-aerodynamic-chord shifts in the center-of-gravity location on the trim angle of attack and trim lift-drag ratio through the range of control deflection angles at $M = 0.60$ for the complete model with the basic wing. A forward shift in center-of-gravity location results in lower values of α_{trim} and higher values of $(L/D)_{trim}$ for a given control deflection and, as might be expected, the opposite is true for a rearward shift in center-of-gravity location.

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CONCLUSIONS

Results of an investigation made in the Langley high-speed 7- by 10-foot tunnel at high subsonic speed to determine the feasibility of using a flap-type control surface to provide longitudinal trim and stability throughout an angle-of-attack range from -2° to 90° on a clipped-delta-wing configuration considered for reentry from orbiting flight indicate the following conclusions:

1. The control arrangement provides longitudinal trim and stability over most of the angle-of-attack range and Mach numbers of the investigation. However, the configuration is unstable at angles of attack from approximately 12° to 24°, especially at the lower Mach numbers.

2. The weight of the control surface should be kept as low as possible so that the rearward shift in center of gravity does not cancel the beneficial aerodynamic effects of deflecting the control.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 20, 1959.

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TABLE I.- GEOMETRIC CHARACTERISTICS OF MODEL

Body:	
Maximum diameter, in.	2.13
Length, in.	10.68
Base area, sq in.	3.18
Wing (basic):	
Span, in.	8.25
Root chord (theoretical), in.	11.40
Tip chord, in.	3.30
Mean aerodynamic chord, in.	8.13
Area, sq ft	0.42
Aspect ratio	1.12
Center of moment area (from wing apex), in.	7.35
Leading-edge sweep, deg	63
Wing (modified):	
Span, in.	8.25
Area, sq ft	0.35
Center of moment area (from wing apex), in.	6.71
Control surface outboard of wing tip (each):	
Span, in.	3.27
Root chord, in.	3.30
Tip chord, in.	2.20
Area, sq ft	0.063
Leading-edge sweep, deg	33.5
Control surface inboard of wing tip (each):	
Span, in.	3.13
Chord, in.	3.30
Area, sq ft	0.072
Vertical tail (each):	
Span, in.	4.00
Root chord, in.	4.50
Tip chord, in.	0.60
Area, sq ft	0.071
Leading-edge sweep, deg	62.8

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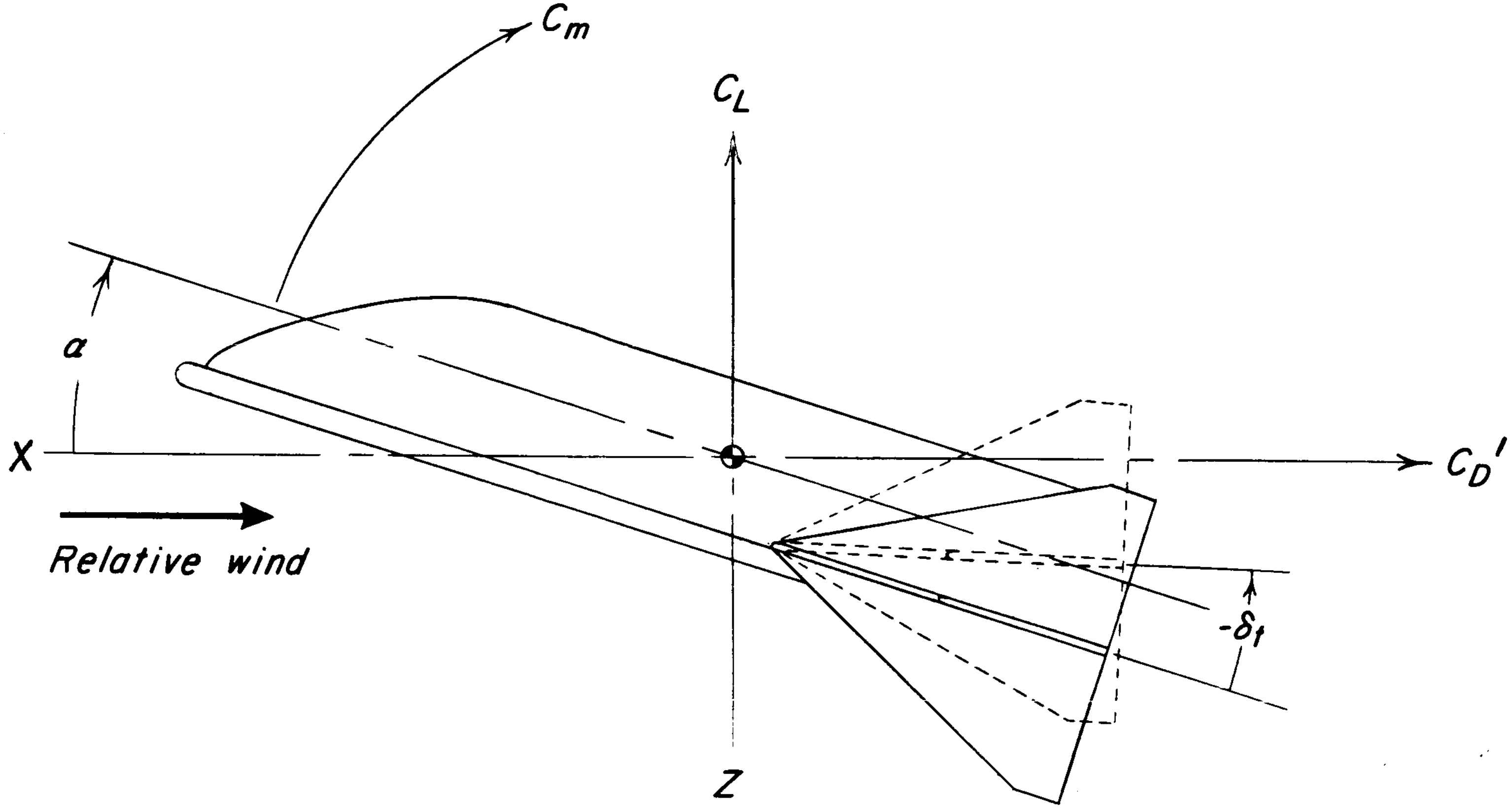
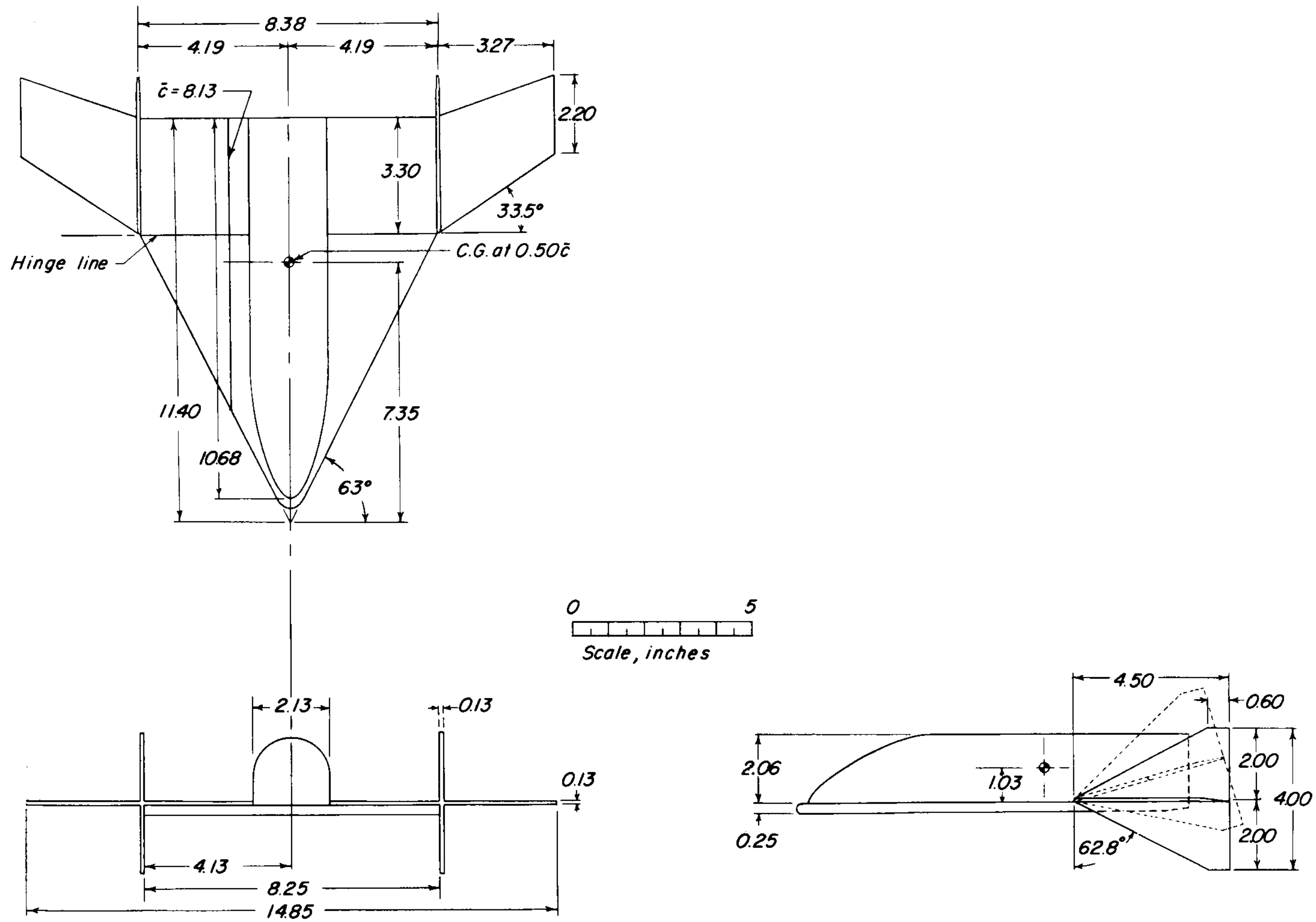
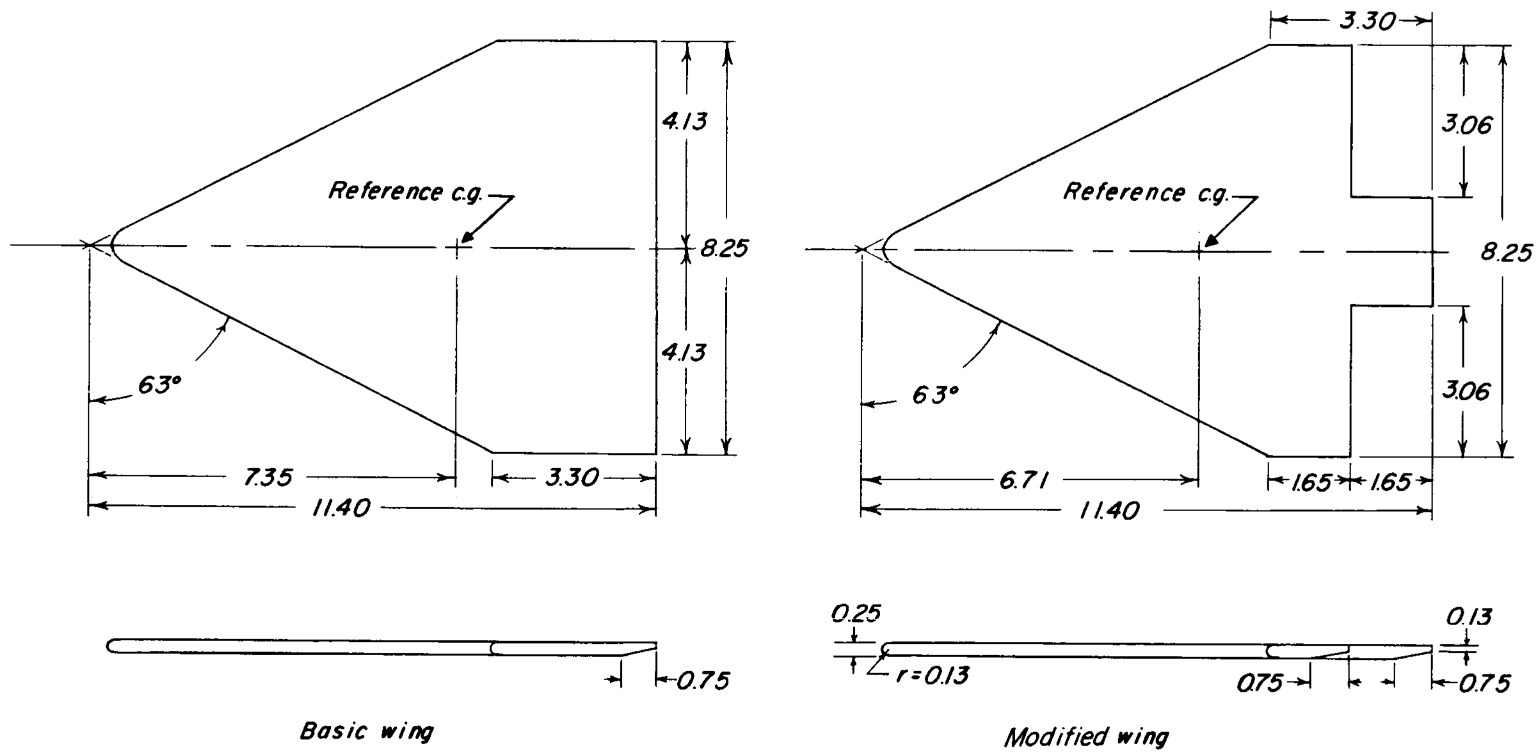


Figure 1.- Stability system of axes showing positive direction of forces, moments, and angles, except where noted.



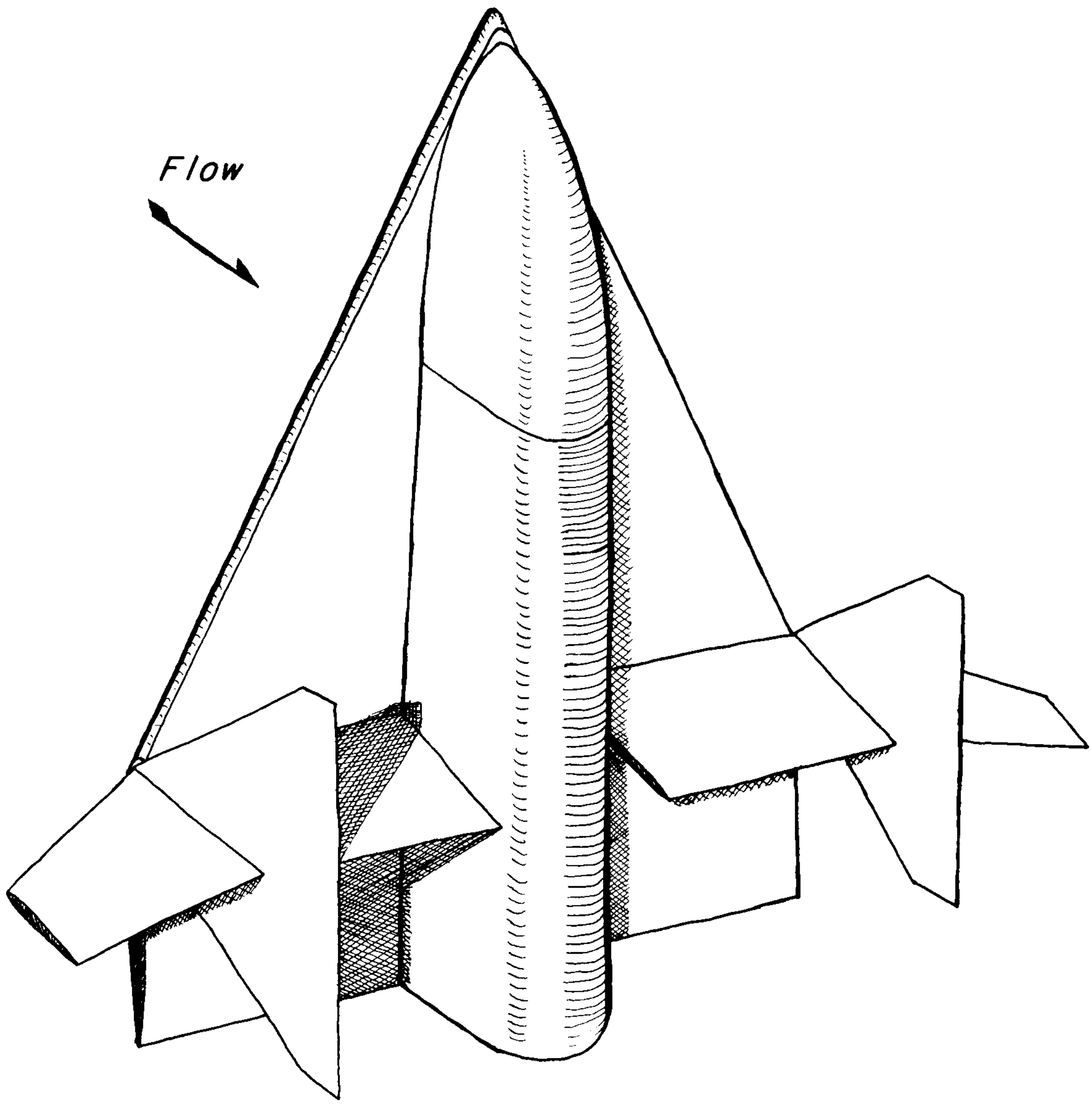
(a) Model.

Figure 2.- Details of model.



(b) Details of wings.

Figure 2.- Continued.



(c) Reentry model. $\delta_t = 90^\circ$.

Figure 2.- Concluded.

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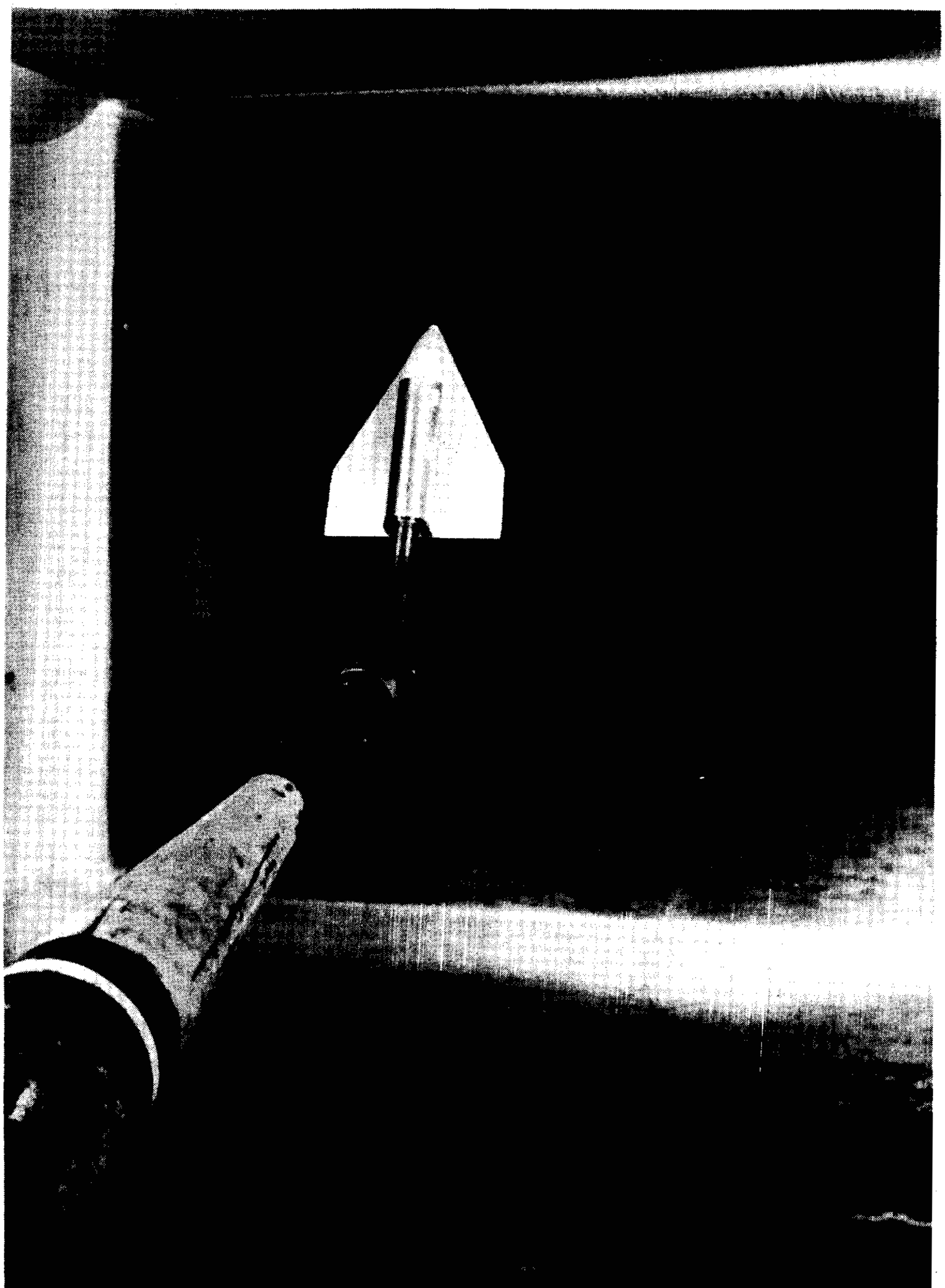

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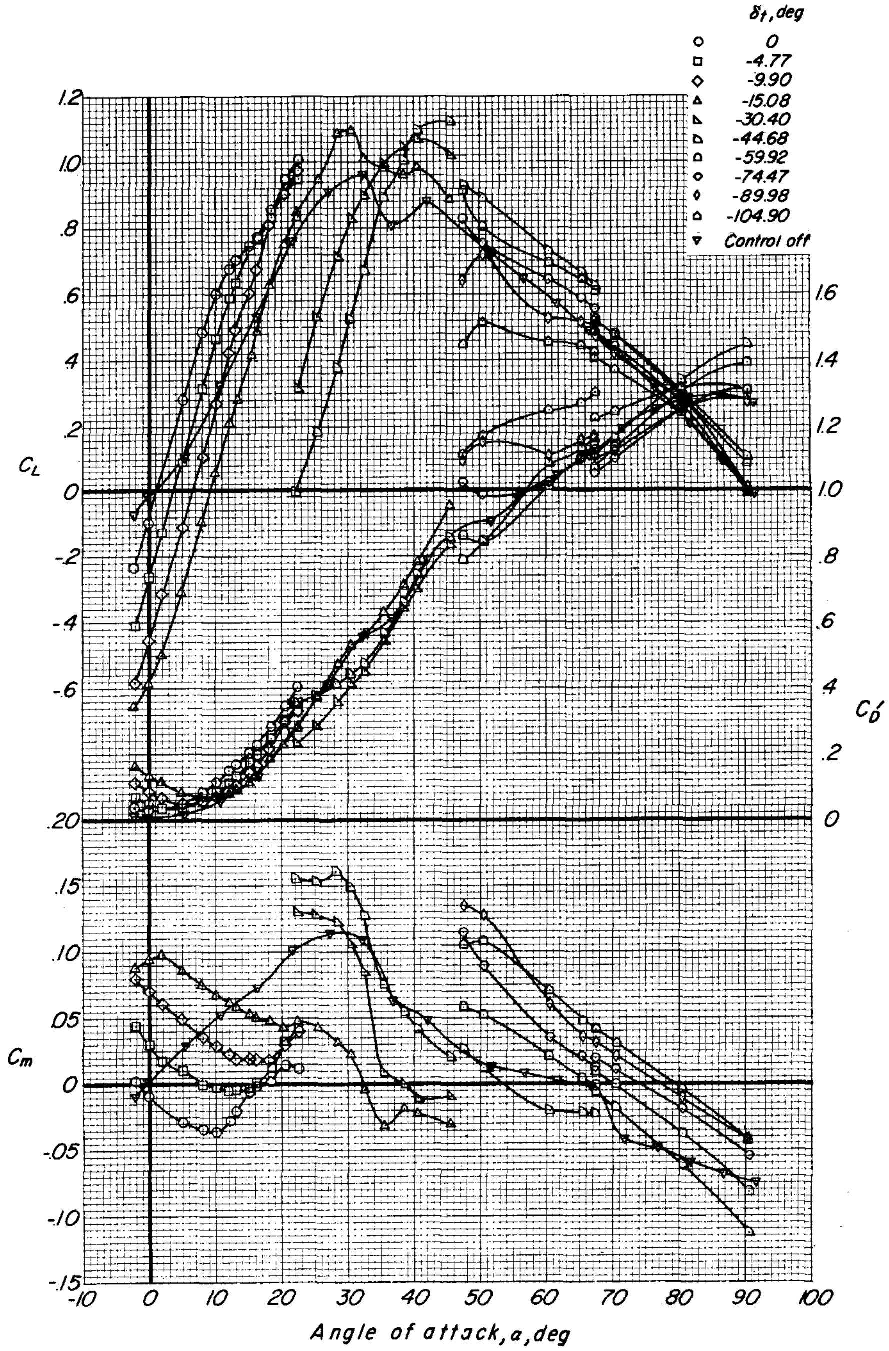
Figure 3.- Photograph of basic wing and fuselage mounted in the Langley high-speed 7- by 10-foot tunnel.



(a) M = 0.60.

Figure 4.- Static longitudinal stability characteristics of model with basic wing.

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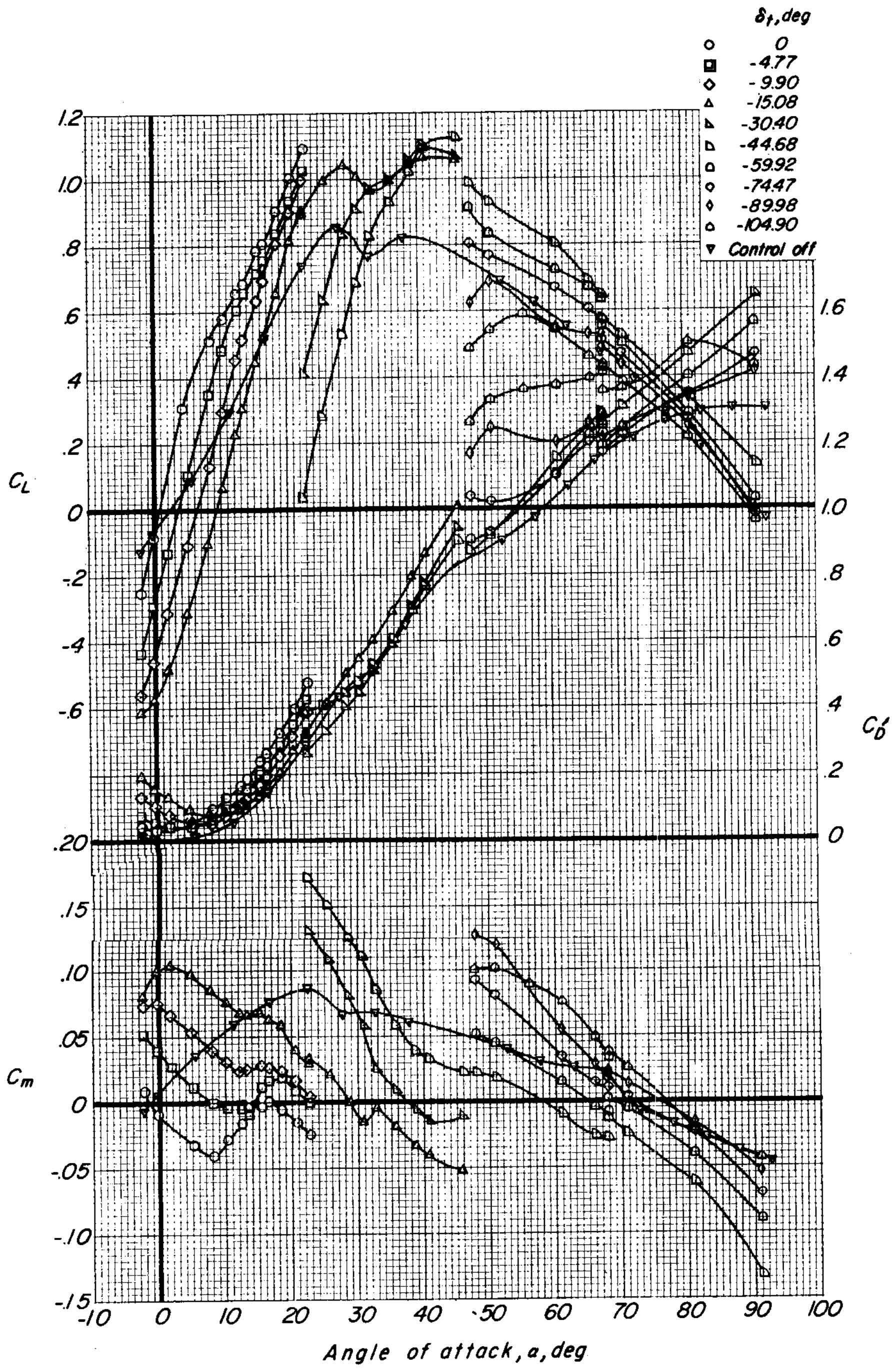
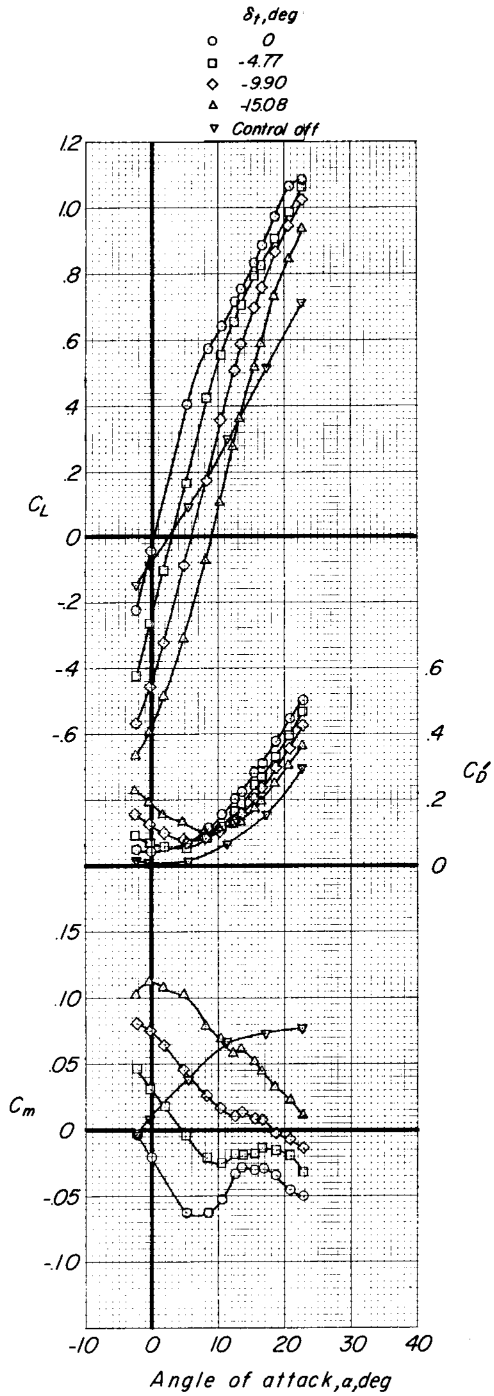


(b) M = 0.80.

Figure 4.- Continued.



(c) M = 0.90.

Figure 4.- Concluded.

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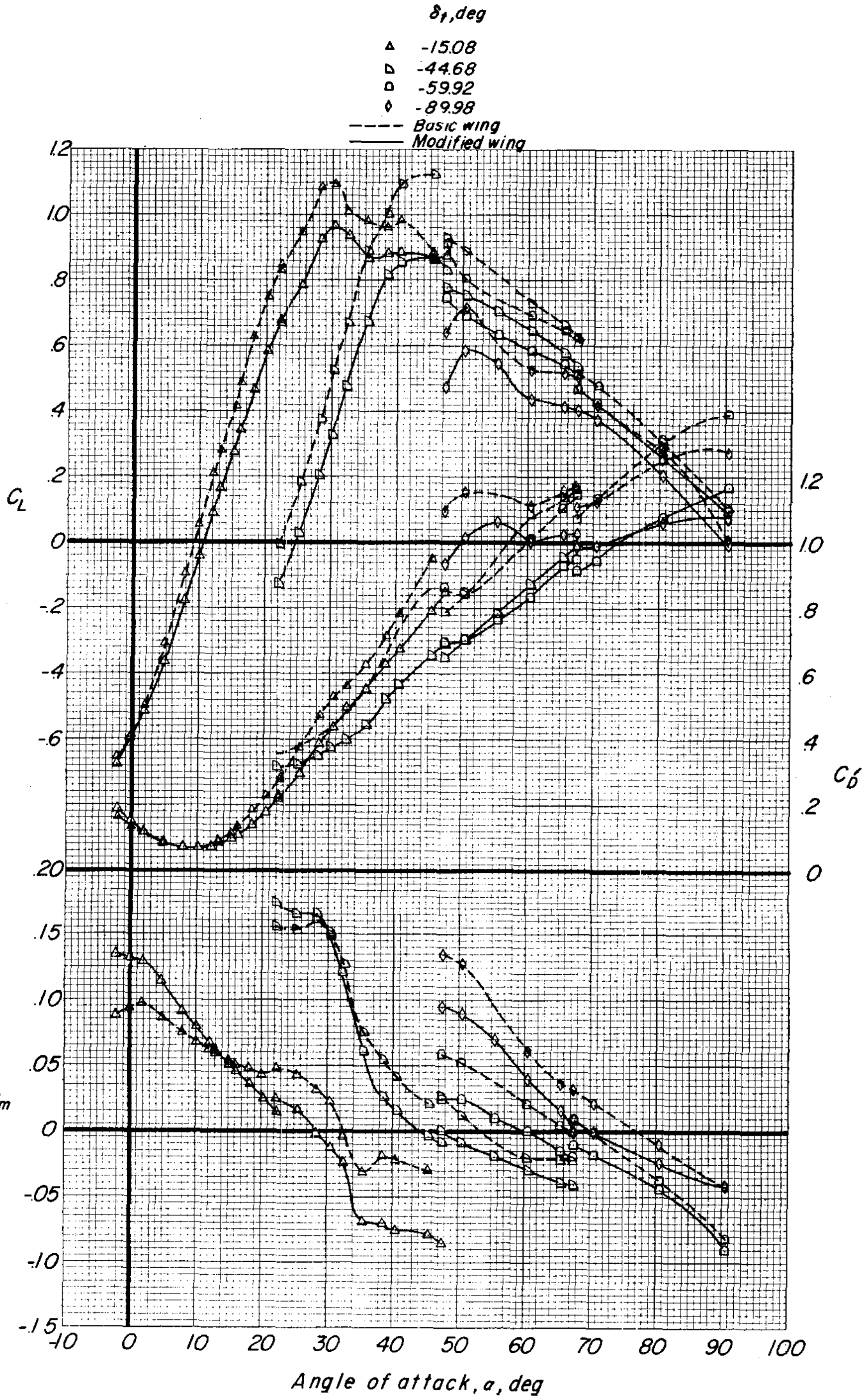

Figure 5.- Static longitudinal stability characteristics of the complete model with basic wing and modified wing at $M = 0.60$.

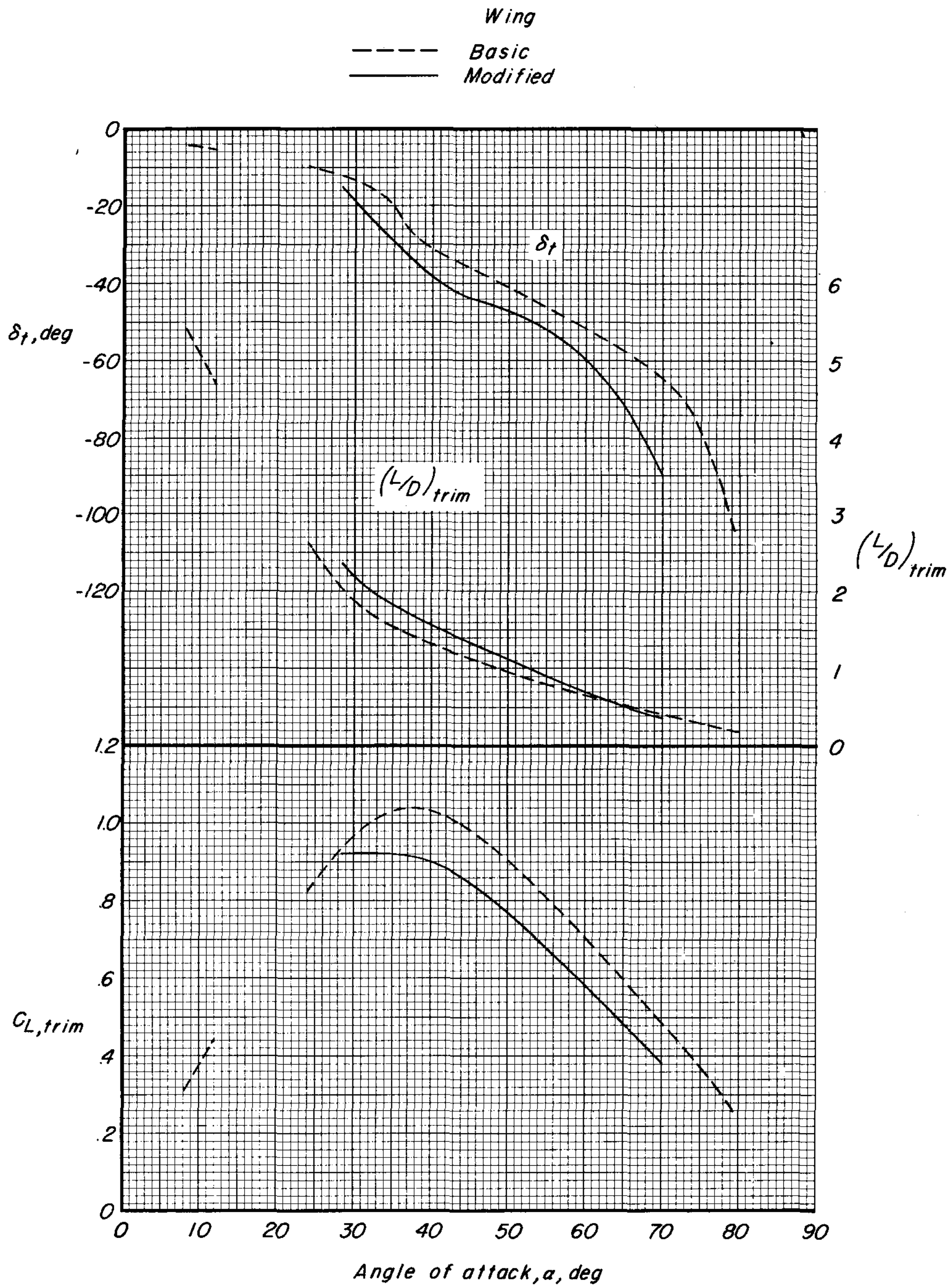

Figure 6.- Variation with angle of attack of the values of trim lift coefficient, trim lift-drag ratios, and control deflection required for trim at $M = 0.60$ for the complete model with basic wing and modified wing.

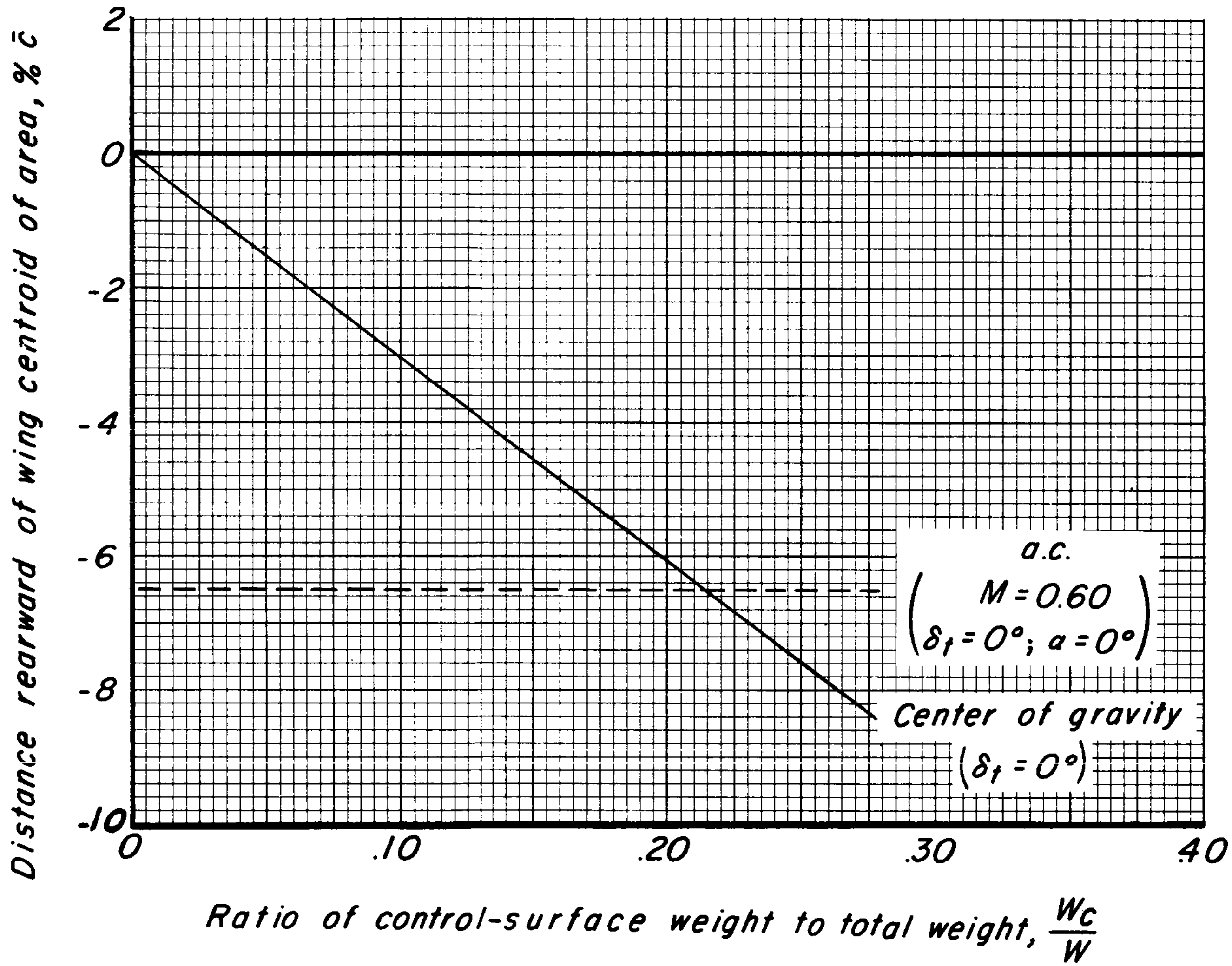

Figure 7.- Effect of control weight on the movement of center of gravity because of change in control deflection from -90° to 0°.

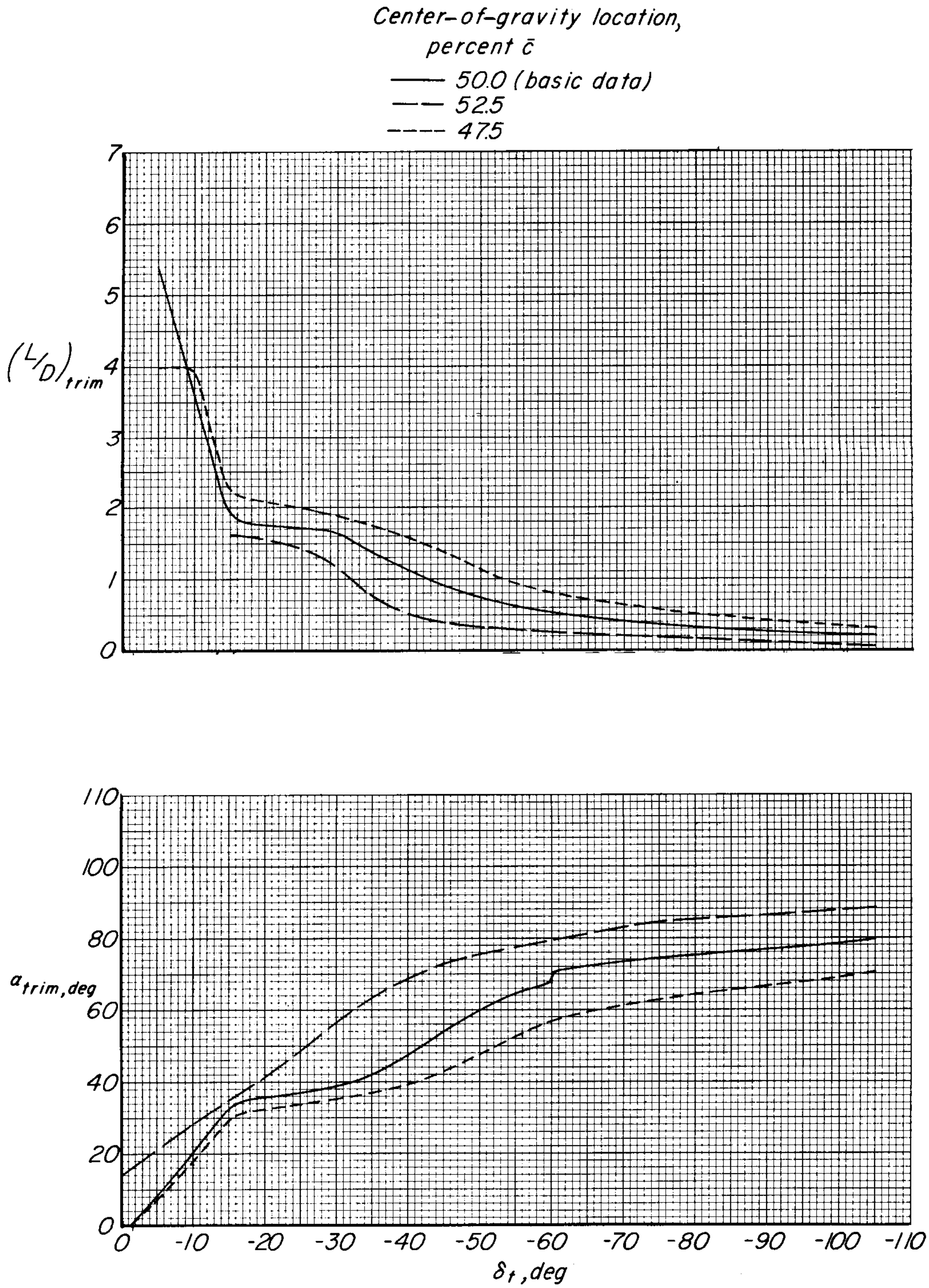

Figure 8.- Effect of 2.5-percent mean-aerodynamic-chord shifts in center-of-gravity location at M = 0.60.